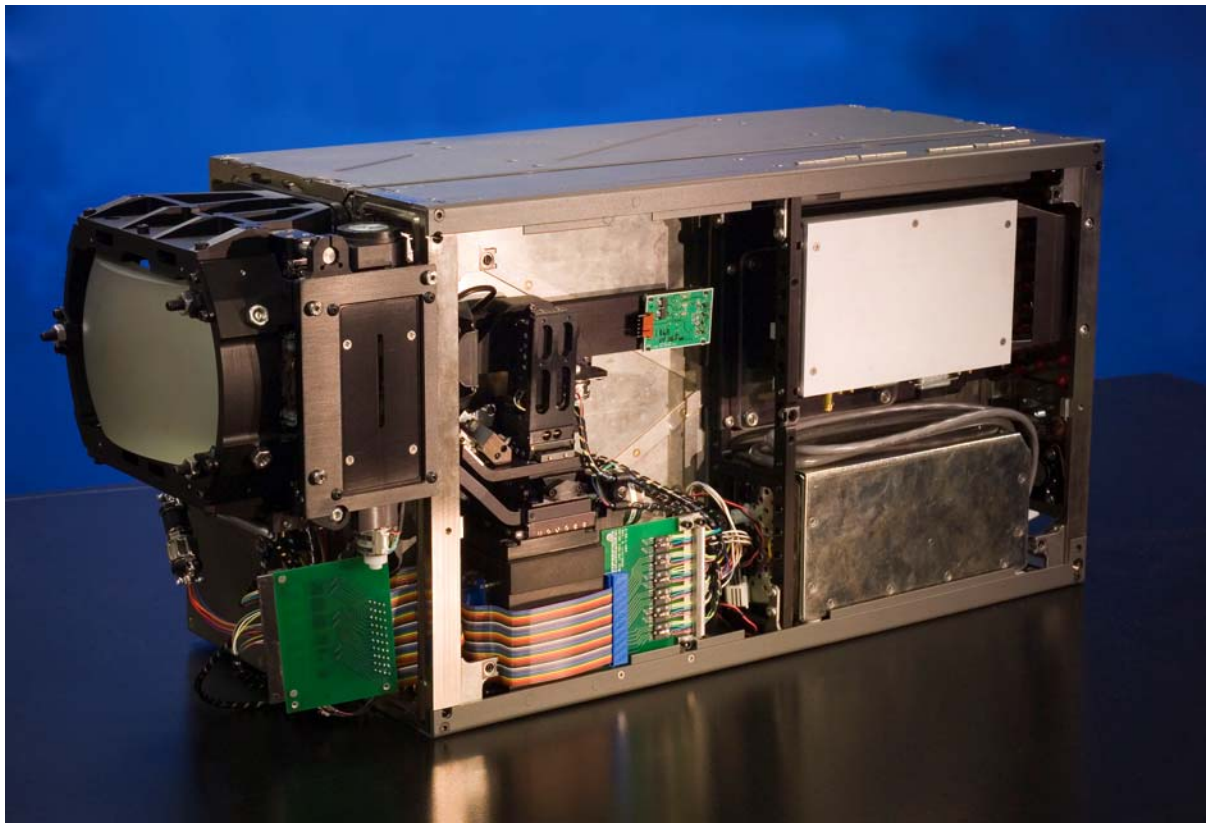
Capabilities for high repetition rate streak cameras

Sydor Instruments



P.A.Jaanimagi, R.Boni and M.Pavia

Sydor Instruments, Rochester NY

SYDOR INSTRUMENTS, LLC

Single-shot, high precision streak cameras can be operated at 10Hz

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- The SNR is reduced at the low end, no impact on the high end
  - fast decay time phosphors are less efficient
- The number of spatial resolution elements is reduced
  - CCD readout is faster with 32x binning in parallel direction
- 20Hz operation possible using a global background frame
  - standard procedure acquires background after each data frame
- Extension to 250Hz with a single channel
  - burst or cw operation

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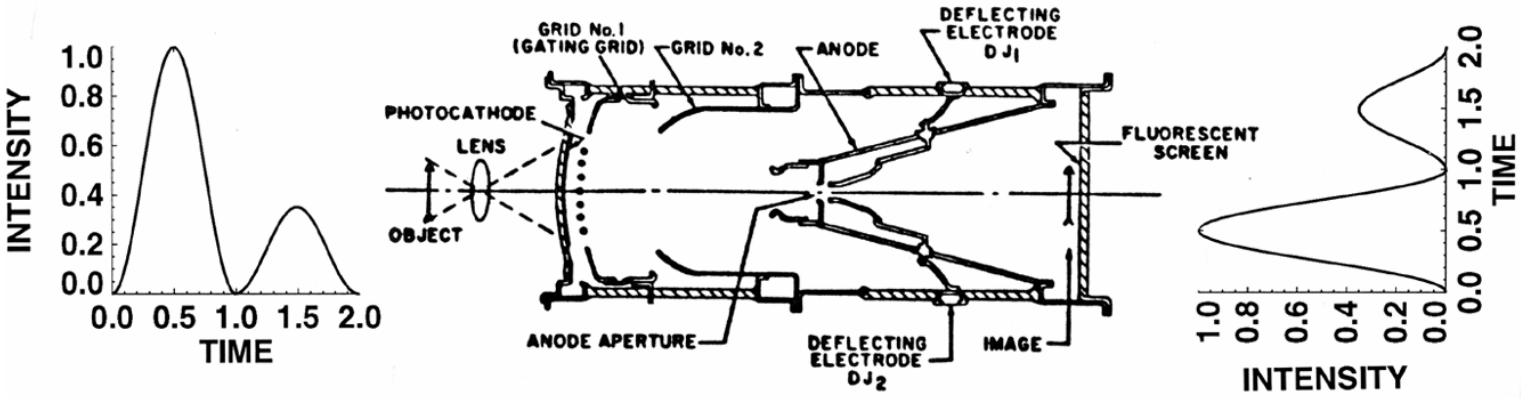
Outline

- **Review single-shot operation of the ROSS camera.**
- **What is different for 10Hz operation?**
- **Options to extend operation to higher frequency.**

Streak cameras are electron-optical imaging devices that convert the time dimension to a spatial dimension



- A line image is projected onto the photocathode, and the photoelectron replica is imaged onto the screen.
- The polarity of an initial dc bias voltage on the deflection plates is reversed as the electron pulse traverses the region, causing the line image to streak across the screen.

The ROSS camera is a comprehensive diagnostic system with autofocusing and self-calibration capability

UR LLE

High-precision measurements require precise setup and calibration of the diagnostic.

The optical calibration module incorporates an extensive imaging, flat-field correction, geometric-distortion and time-calibration capability.

All functions can be accessed and monitored remotely.

Rochester Optical Streak System technology has been transferred to Sydor Instruments

All pixels in the recorded image were not created equal

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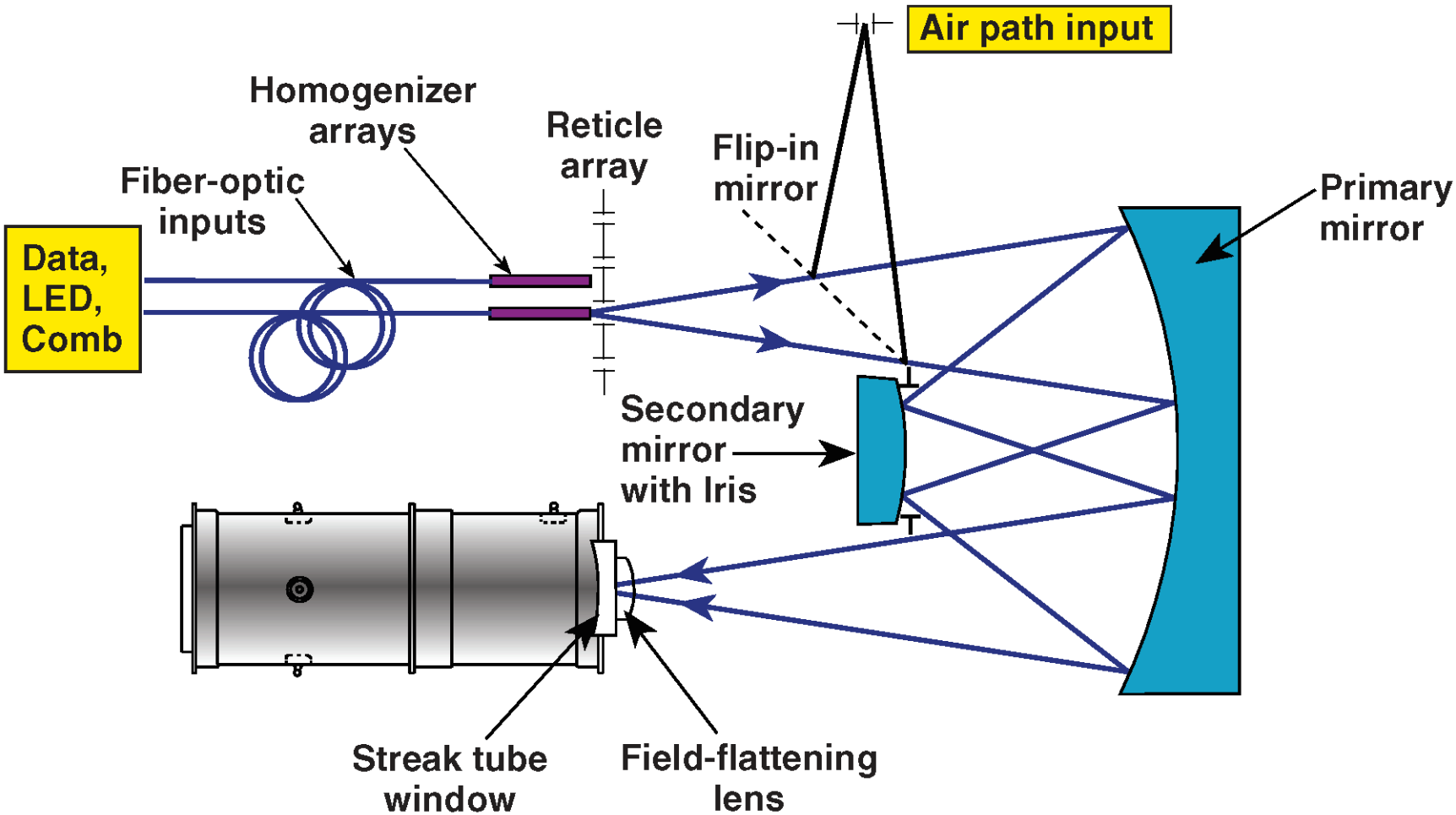
The system response is dependent on the spatial and temporal position and the focusing conditions.

To make pretty pictures and FWHM measurements requires minimal calibration.

Serious quantitative measurements, (SNR > 10, DR > 10, nonlinearity < 10%), require extensive calibrations.

These issues are addressed in the ROSS design with the Optical Calibration Module.

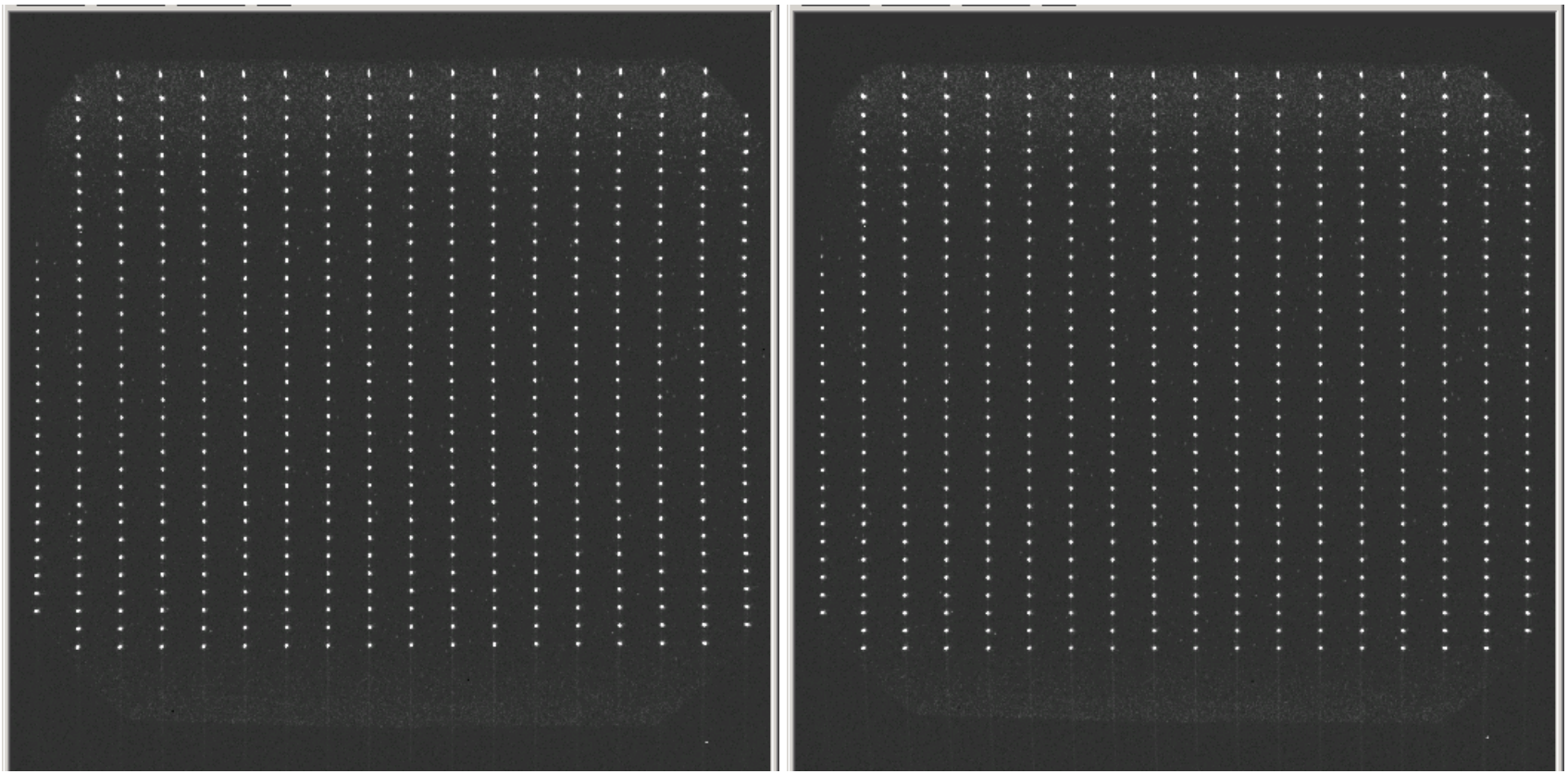
The input imaging system is an Offner triplet with motorized controls for the dual object planes and the secondary mirror



E13258

Geometric distortion correction of the P820-26 streak tube has spots aligned to 0.49 ±0.32 pixels

Reticle has 10μm openings on 400μm centers, LED is pulsed at 5Hz.



Space ⇑

Time ⇒

5th order polynomial correction

Flat-fielding a CCD recording system elevates its performance to a near-quantum-limited detector

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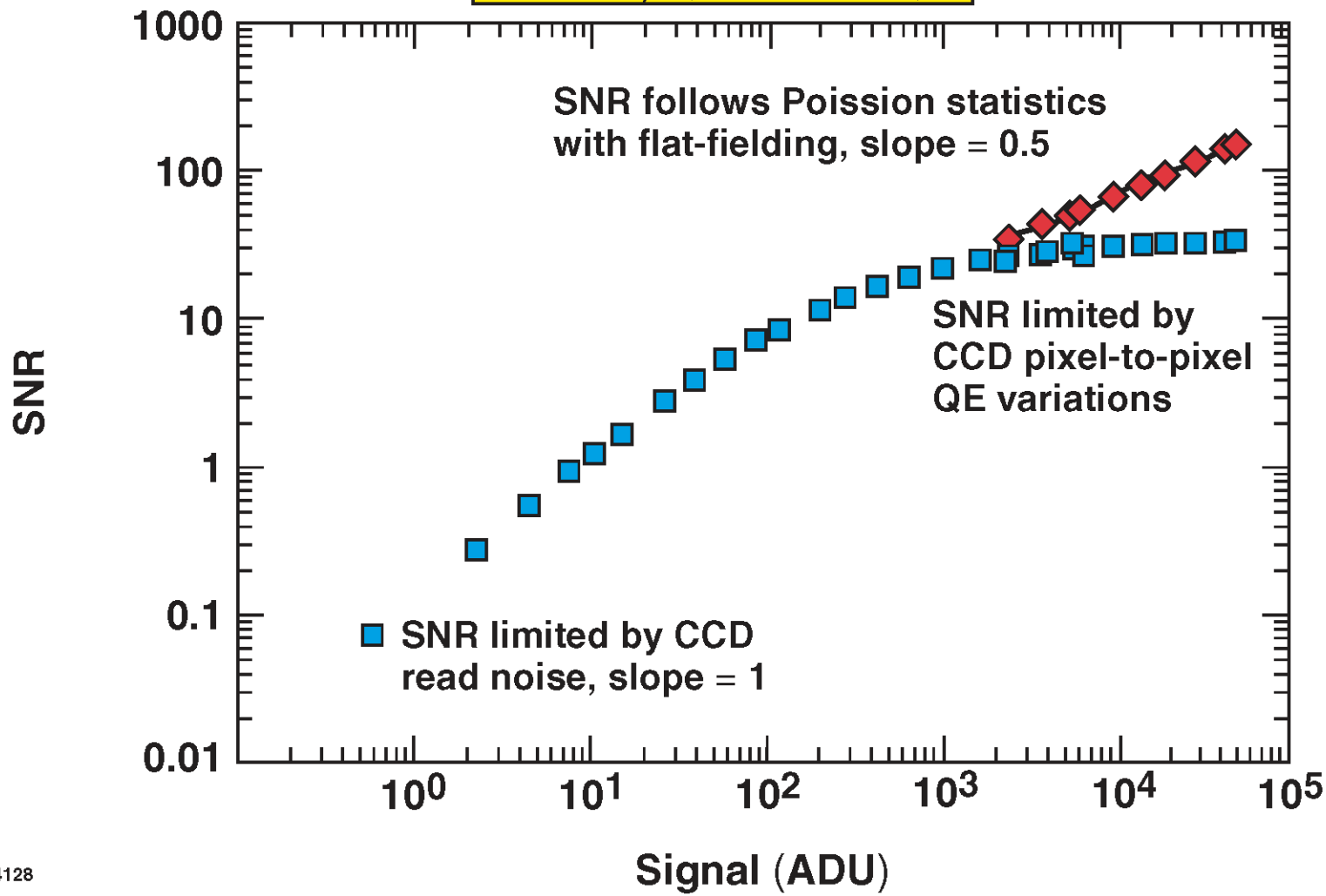
$$SNR = S \Big/ \left(S + N_R^2 + I_d t\right)^{1/2}$$

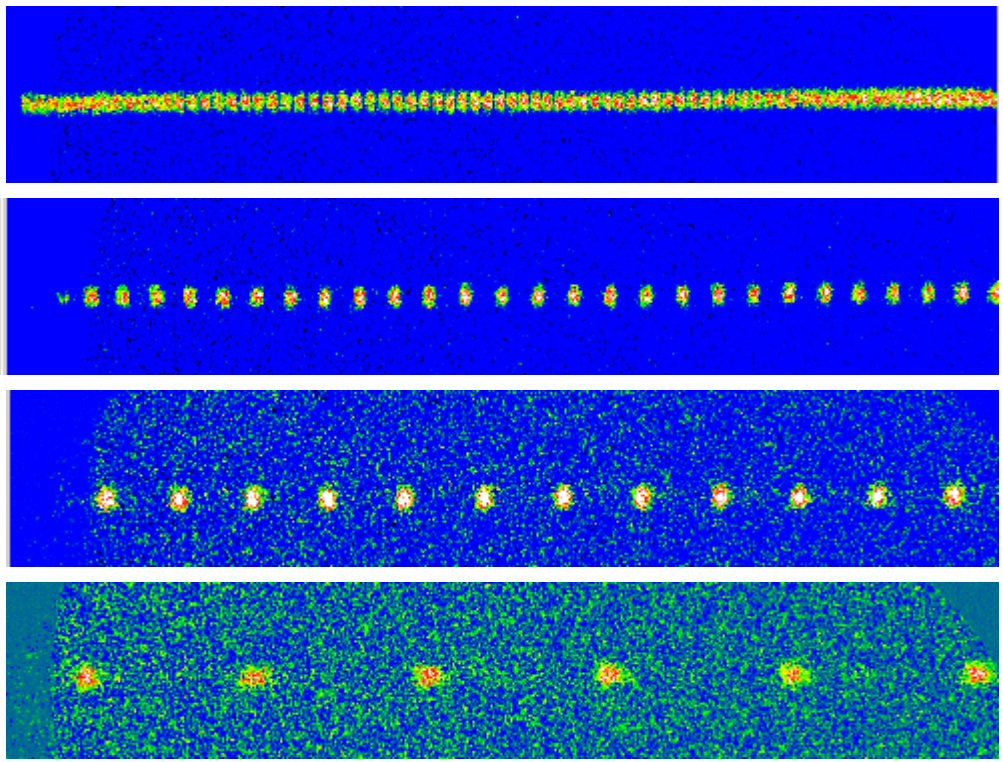


E14128

Time calibration is accomplished with an on-board 664nm, 2GHz comb generator

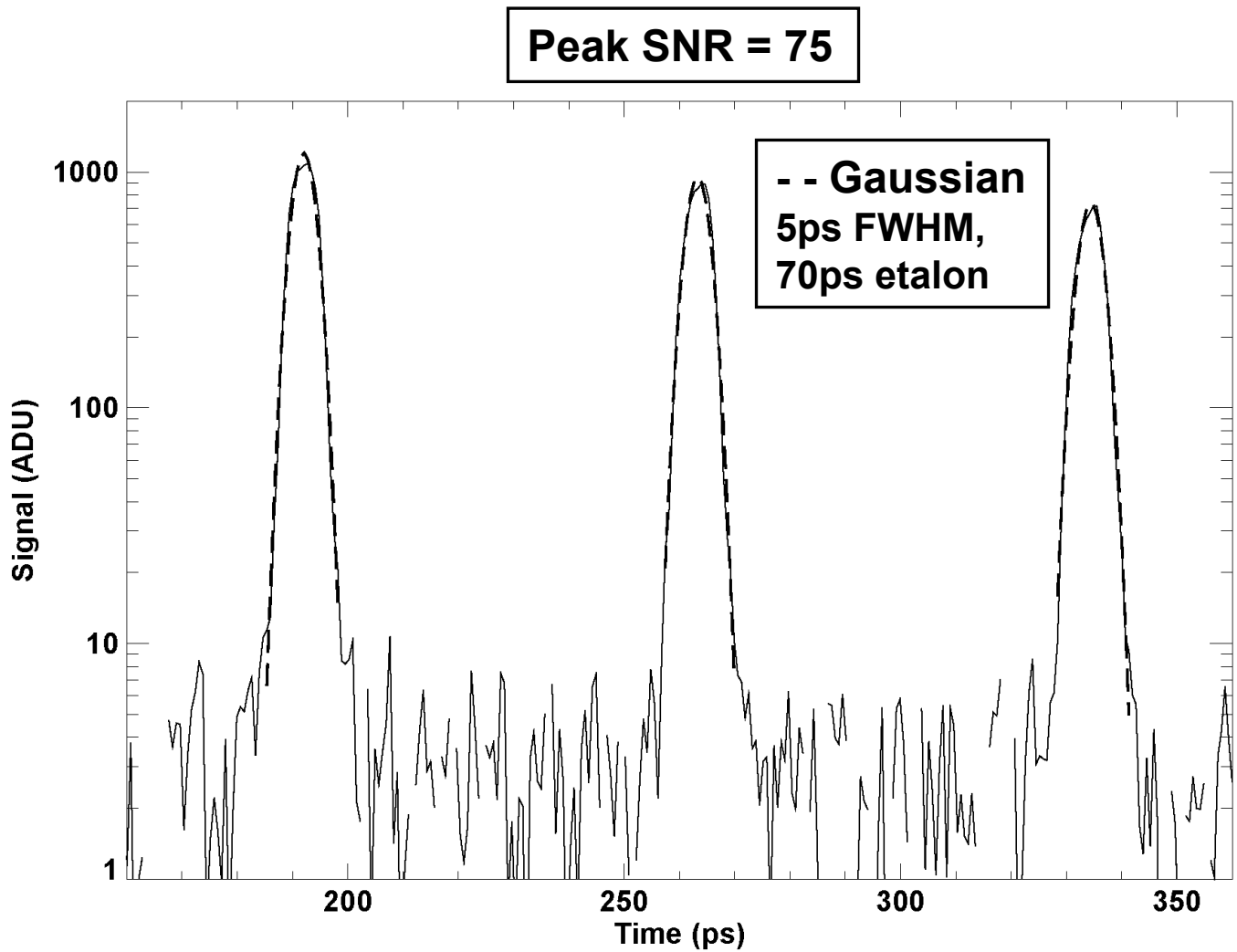
Verify system operation prior to shot.

An external source may also be coupled into any or all channels.



4 streak speeds, (2-25ns), can be selected remotely

The P820 streak tube provides a 2ps time resolution capability for OMEGA-EP diagnostics



Traps in the CCD can produce a latent image and result in an artificial offset for the background level

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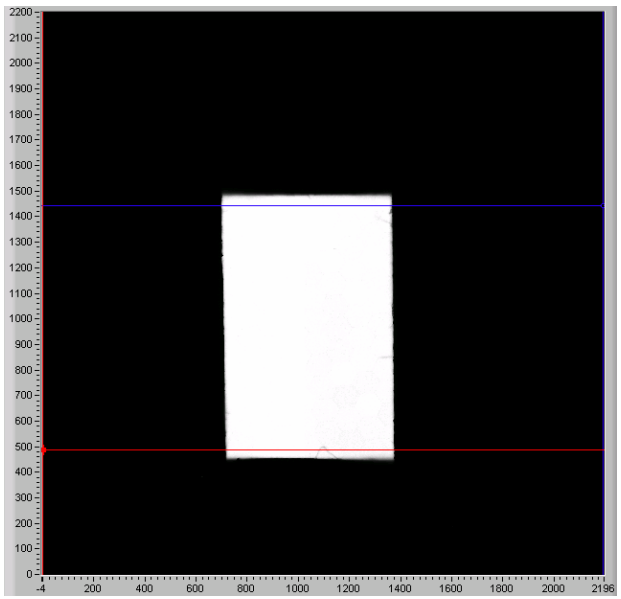
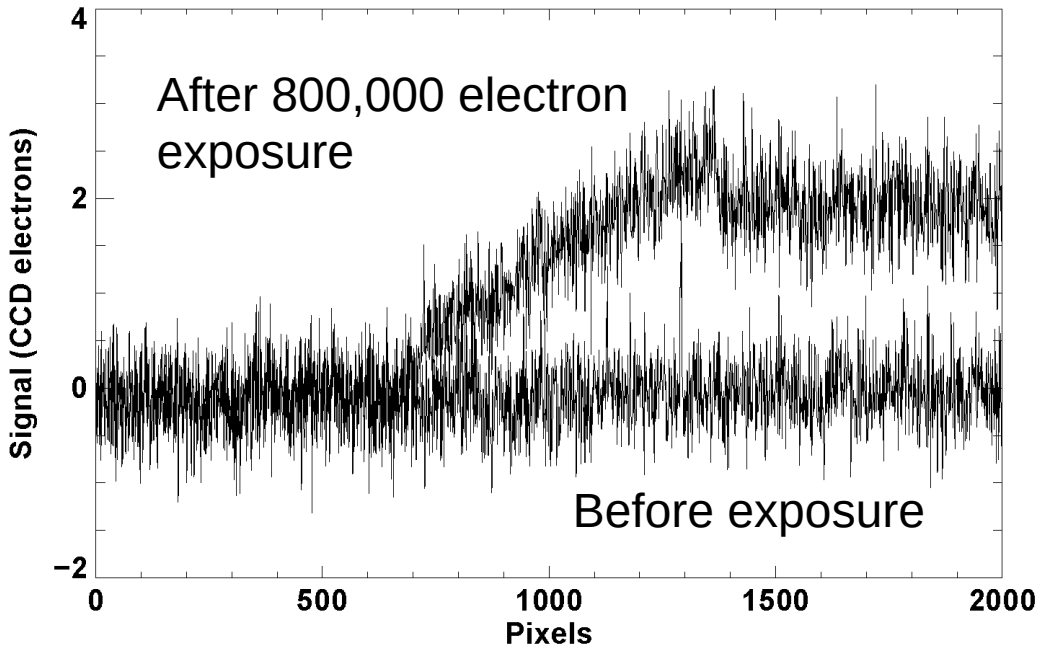
- A fraction (10^{-3} to 10^{-4}) of the CCD electrons are trapped in the wells.
- At -40ºC, they are thermally released with a 45 minute time constant.



⇐ Parallel shift direction

2 s exposure, 24 s readout time



A.Rest, et al. RSI 73, 2028 (2002)

The major components of a streak camera must be re-evaluated for high repetition rate operation

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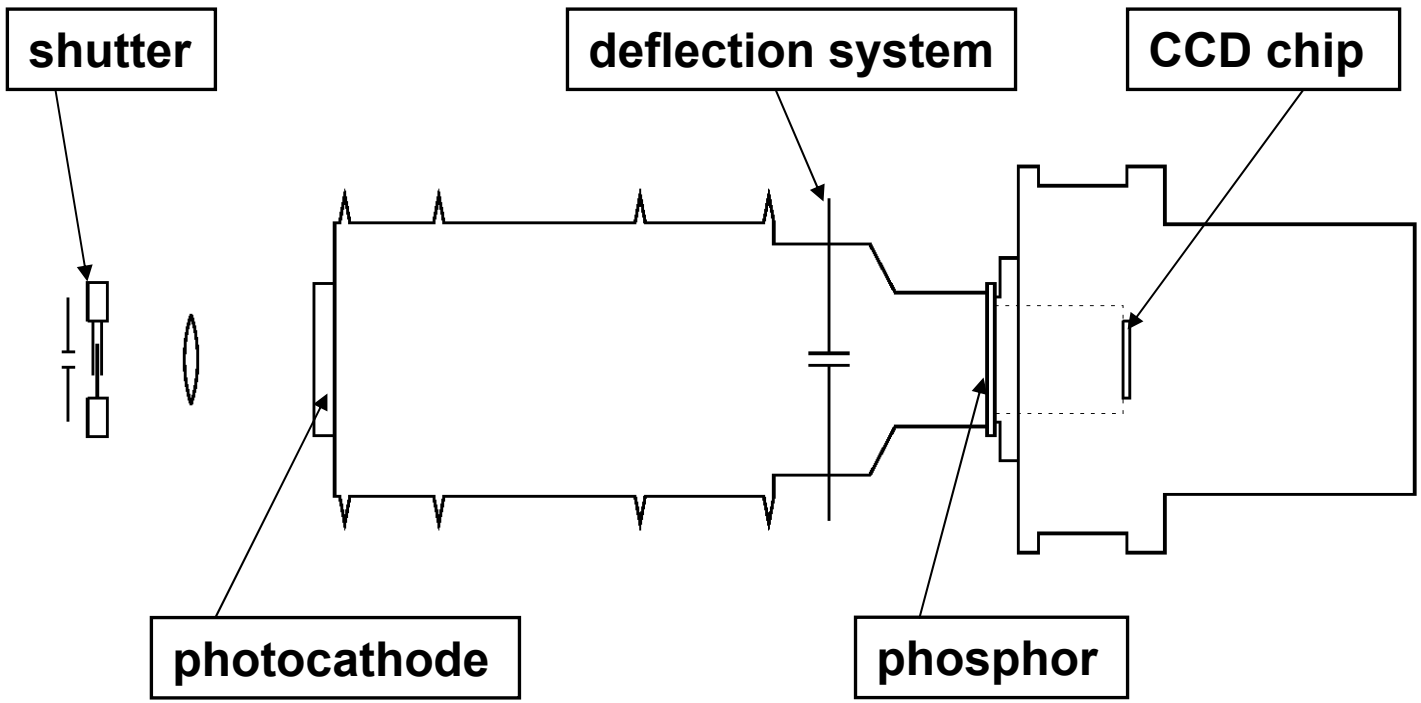

Mechanical shutters have limited operational bandwidth

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Diameter (mm)	2	3	6	25
Maximum freq. (Hz)	100	50	20	5

Uniblitz LS Series

Irising shutters must be replaced often – disposable item.

<u>Solution:</u>

Use a slot in a rotating disc.

Need sensors and controls to synchronize the opening with the external event.

Photocathodes may become a maintenance item

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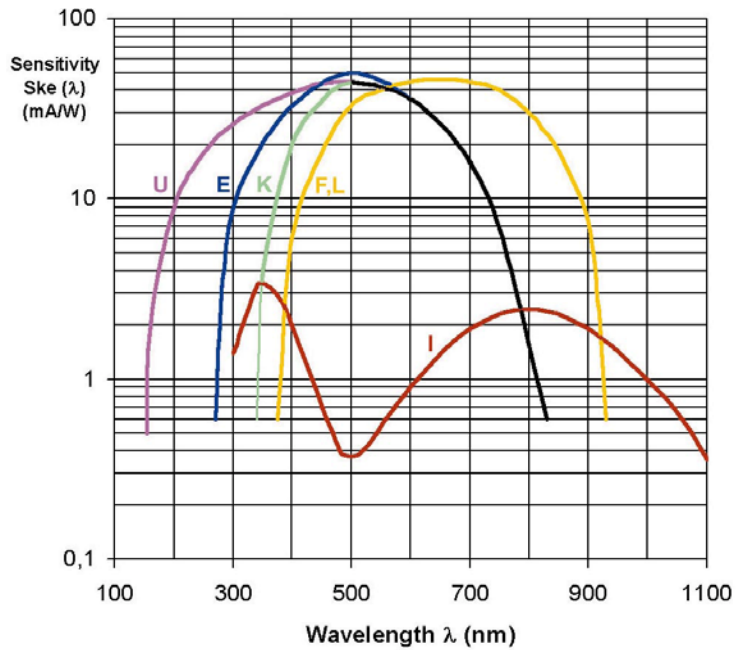
Photocathodes are thin, resistive films with limited thermal conductivity.

The main failure mode is loss of QE due to ion feedback from the residual gas in the tube. High rep. rate usage will accelerate the degradation.

Expected lifetime < 5 years.



Standard deflection plate drive circuits also have limited operational bandwidth

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- **Avalanche transistor stacks switching ±1kV into 50Ω**
  - **10Hz rep. rate OK, at 100Hz the voltage will droop**
  - **lifetime is unknown, > 10^7 cycles**

Solution A:

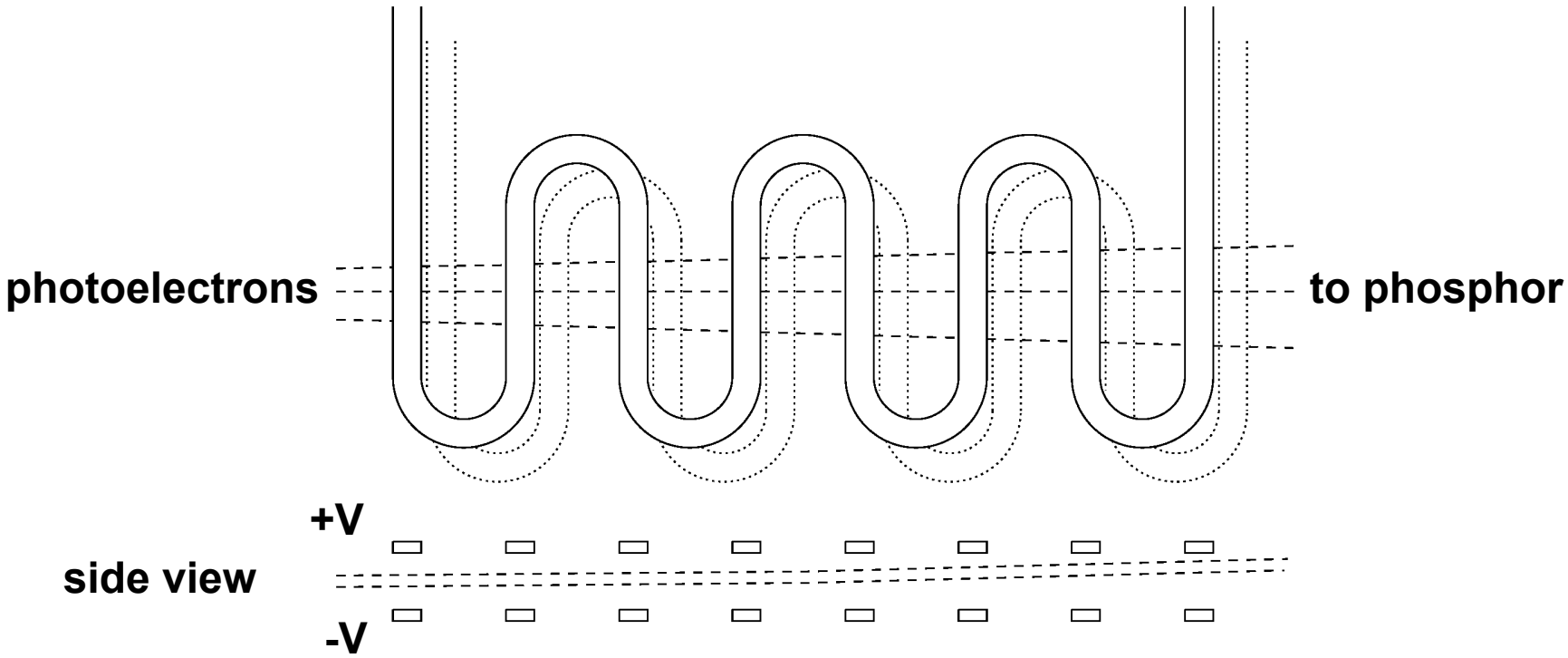
- **Semiconductor switches have operated at 1kHz.**
  - **need 100μJ of optical energy per switch**
  - **very low jitter**

Solution B:

- **Travelling-wave deflection**
  - **lower voltage and fewer components**

Travelling-wave deflection systems have higher bandwidth and higher deflection sensitivity

A 50Ω stripline in a meander configuration may require only ±100V transients.



Electron beam velocity is in phase with the propagation speed along the stripline.

A fast decay time phosphor and a faster readout CCD must replace the standard ROSS recording system

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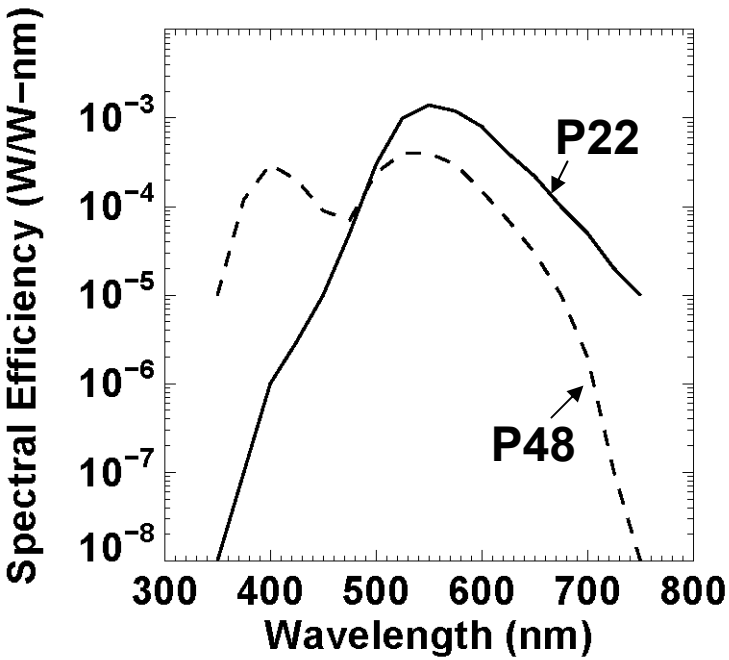
P22 has ms decay time + long low level tail

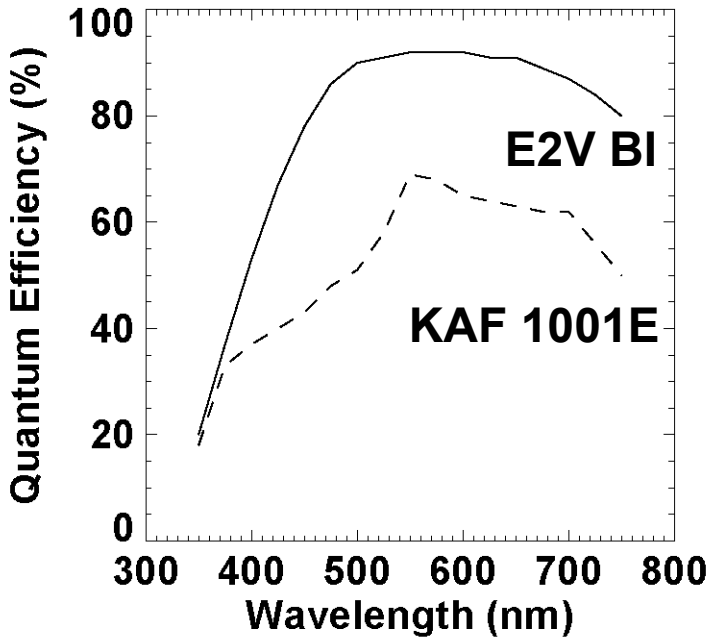
P48 has 100ns decay time

Parallel shift overhead:

E2V 42-40BI ⇒ 100ms

KAF 1001E ⇒ 15ms





The high rep. rate recording system has 5X lower gain

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	P22 + E2V 42-40BI	P48 + KAF 1001E
Gain (CCD e^- / pe^-)	100	20
# Pixels	2048 x 2048	1024 x 1024
Pixel size (μm)	13.5	24.0
Array size (mm)	27.65	24.58
Parallel shift (μs)	50	15
N_{read} (e^-) 400kHz	5	8
I_{dark} (e^-/pixel/s)	0.05 (-40°C)	0.6 (-30°C)

The streak camera performance at 10Hz is still limited by the streak tube

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Divide the CCD into 2 channels and consider a 20ns streak @ 0.1ma / channel $\Rightarrow$ <u>12500 photoelectrons / channel / 20ps pixel</u>

Binning is 256 x 1 or 2 superpixels / channel.

At 400kHz the 8 electron single pixel read noise increases to $N_{read} \approx 55$ electrons / superpixel with background subtraction.

The rms system noise is equivalent to

<u>4 photoelectrons / channel / 20ps pixel</u>

SNR_{peak} = sqrt(12500) $\approx$ 100, dynamic range = 12500 / 4 $\approx$ 3000

Low end signals are limited by the recording system.

Are there alternative recording systems?

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Frame transfer CCD

- twice the parallel transfers, twice the area

Electron-multiplying CCD

- only small area CCD's available, noise factor

CMOS

- gain non-uniformity, lower QE and higher read noise

Hybrid CCD-CMOS

- new, attractive option

Electron-bombarded CCD

- no phosphor, high gain

- issues with tube processing and HV static discharges

- E.D.Savoye et al., SPIE 203, 59 (1979)

Can we increase the streak camera rep. rate?

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Cummulative mode:

- **Synchroscan @ 76MHz mode-locked laser frequency**
  resonant LC circuit to drive the deflection plates
  M.C.Adams et al., Opt. Comm. 26, 273 (1978)

- **Semiconductor switching at 1kHz, recombination limited**
  low jitter allowed the detection of ps pulses
  G.Mourou and W.Knox, APL 35, 492 (1979)

Circular scan:

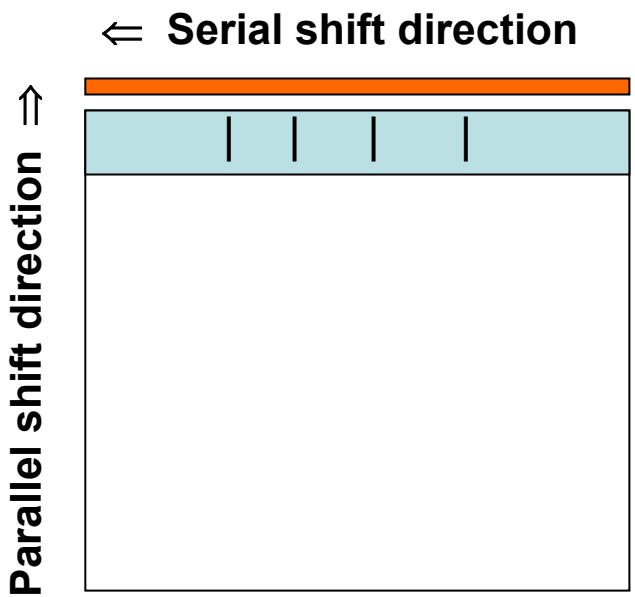
- **2 orthogonal sets of deflection plates, RF 90° out of phase**
  E.K.Zavoiskii and S.D.Fanchenko. Appl. Opt. 4, 1155 (1965)
  C.B.Johnson, et al., Appl. Opt. 19, 3491 (1980) – annular Reticon

A CCD camera can be used as a slow scan streak camera during the readout phase. (dual-axis streak)

Record a single channel streak in the first N rows of the CCD

Bin N rows together in the serial register

During digitization, streak the next event into the first N rows



KAF 1001E with N=100

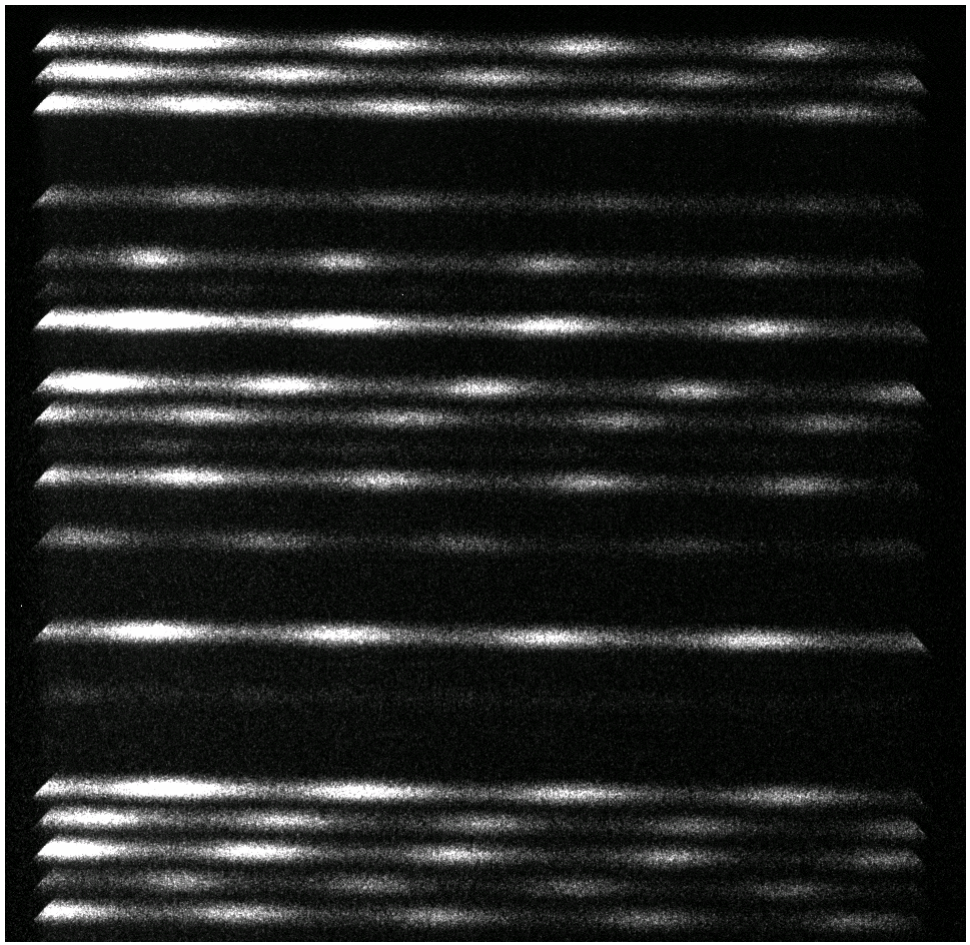
Parallel shift 15μs x 100 = 1.5ms

1000 ADC @ 400kHz = 2.5ms

Single channel streaks @ 250Hz

Operate c.w. or in burst mode collecting a full frame of data

5Hz burst mode operation of a ROSS camera during the CCD readout using the parallel shift to isolate individual streaks



Parallel shift direction ⇑

The CCD is being used as a slow sweep streak camera in the parallel direction

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